## HAT Variability Survey in the High Stellar Density "Kepler Field" with Millimagnitude Image Subtraction Photometry.

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## **ABSTRACT**

The Hungarian-made Automated Telescope network (HATnet) is an ongoing project to detect transiting extra-solar planets using small aperture (11 cm diameter), robotic telescopes. In this paper we present the results from using image subtraction photometry to reduce a crowded stellar field observed with one of the HATnet telescopes (HAT-5). This field was chosen to overlap with the planned Kepler mission. We obtained I-band light curves for 98,000 objects in a 67-square-degree field of view centered at  $(\alpha, \delta) = (19^{\rm h}44^{\rm m}00^{\rm s}0, +37^{\circ}32'00''0)$  (J2000.0), near the Galactic plane in the constellations Cygnus and Lyra. These observations include 788 5-minute exposures over 30 days. For the brightest stars (I  $\sim 8.0$ ) we achieved a precision of 3.5 millimagnitudes, falling to 0.1 magnitudes at the faint end (I  $\sim$  14). From these light curves we identify 1617 variable stars, of which 1439 are newly discovered. The fact that nearly 90% of the variables were previously undetected further demonstrates the vast number of variables yet to be discovered even among fairly bright stars in our Galaxy. We also discuss some of the most interesting cases. This includes: V1171 Cyg, a triple system with the inner two stars in a P = 1.462 day period eclipsing orbit and the outer star a P = 4.86 day Cepheid; HD227269, an eccentric eclipsing system with a P = 4.86 day period that also shows P = 2.907 day pulsations; WW Cyg, a well studied eclipsing binary; V482 Cyg, an RCB star; and V546 Cyg, a PV Tel variable. We also detect a number of small amplitude variables, in some cases with full amplitude as low as 10 mmag.

Subject headings: techniques: photometric — catalogs — binaries: eclipsing – Cepheids — delta Scuti — stars: variables: other

## 1. Introduction

The Hungarian-made Automated Telescope network (HATnet) is an ongoing project to detect transiting extra-solar planets using small aperture (11 cm diameter), robotic telescopes (Bakos et

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al. 2004, hereafter B04). The HATnet telescopes make use of a fast focal ratio (f/1.8) to efficiently monitor a large number of fairly bright stars (I < 14.5) over a wide field-of-view (FOV). A number of other groups have also taken this small-telescope approach toward finding transits (see Horne 2003 for a comprehensive list). In contrast, there are several groups that employ a "narrow, but deep" method. This includes the transit search by the Optical Gravitational Lensing Experiment (OGLE) project, which to date has discovered three confirmed "very hot Jupiters" (Udalski et al. 2002, 2003; Konacki et al. 2003; Torres et al. 2004; Bouchy et al. 2004; Konacki et al. 2004), the only planets detected so far by transit searches.

Besides the size of the telescopes and FOV, another difference between the approaches is the method used to obtain photometry for the monitored stars. For several years many of the "narrow and deep" searches have made use of the image subtraction techniques due to Alard & Lupton (1998; also Alard 2000). This includes OGLE which uses Difference Image Analysis (DIA, Wozniak 2000), and PISCES (Mochejska et al. 2002, 2004) which uses a different implementation of image subtraction in monitoring the open clusters NGC 2158 & NGC 6791.

Image subtraction is the current state of the art for massive time-series photometry. It has been shown that in narrow, dense fields, it can produce light curves with precision down to the photon limit (e.g. see Mochejska et al. 2002). However, to date there exists no published results that use image subtraction in a wide-field setting. This has limited these searches to observing only relatively isolated stars in regions where point spread function (PSF) fitting and aperture photometry yield high precision.

In this paper we report our use of image subtraction to obtain light curves for 98,000 objects in a single field, near the galactic plane, observed with one of the HATnet telescopes (HAT-5). This field was chosen in particular because of its overlap with NASA's *Kepler* mission to observe transiting planets from space (Borucki et al. 2003). Over 9,000 of the brightest light curves have a root-mean-square (RMS) of less than 1% (i.e. better than 10 millimagnitude precision) at 5-min sampling. In the following section we describe our observations, and in §3 we discuss our image subtraction based data reduction to obtain the light curves.

While the main purpose of HATnet remains the discovery of transiting extra-solar planets, it is also useful for discovering and characterizing variable stars in the Galaxy. To this end we have analyzed these light curves to select a list of 1617 variable stars, of which 1439 are newly discovered. We describe our selection criteria in §4 and present our catalog, including a discussion of many interesting cases, in §5. We finish with a brief summary of our results in §6.

## 2. Observations

The data were obtained in June and July, 2003 using the HAT-5 telescope located at the Fred Lawrence Whipple Observatory (FLWO). The telescope uses a Canon 11 cm diameter f/1.8L lens and a Cousins I-band filter to image onto an Apogee AP10 front-illuminated,  $2K \times 2K$  CCD.

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subjecting the heat-treated member to an aluminum or silicon diffusion coating includes subjecting said member with said Cr and Al films to an aluminum diffusion coating at a given high temperature to allow said Cr and Al films to be formed as a Cr-aluminide layer.

- 5. (Original) The method as defined in claim 3, which includes the step of forming a Re film and an Al film on said inner layer of the Re-Cr based σ (sigma) phase, wherein the step of subjecting the heat-treated member to an aluminum or silicon diffusion coating includes subjecting said member with said Re and Al films to an aluminum diffusion coating at a given high temperature to allow said Re and Al films to be formed as a Re-aluminide layer.
- 6. (Original) The method as defined in claim 3, which includes the step of forming a Re film on said inner layer of the Re-Cr based  $\sigma$  (sigma) phase, wherein the step of subjecting the heat-treated member to an aluminum or silicon diffusion coating includes subjecting said member with said Re film to a silicon diffusion coating to allow said Re film to be formed as a Re-silicide layer.
- 7. (Previously presented) A method for producing a metal-based resistance heatgeneration element excellent in heat resistance and high-temperature corrosion resistance, comprising the steps of:

Amendment under 37 CFR § 1.116 Application No. 10/519,802 Attorney Docket No. 043061

forming a material made of a platinum-group metal or refractory metal into a shape of a heat-generation element member;

coating on all surfaces of said heat-generation element member with a film made of a Re-Cr alloy or a bilayer film consisting of a Re layer and a Cr layer, thereby obtaining a film-coated member;

heat treating said film-coated member to diffuse Re and Cr into said member so as to convert said member into a platinum-group or refractory metal-Re-Cr alloy, thereby obtaining an alloyed layer; and

subjecting said alloyed layer to an aluminum or silicon diffusion coating so as to form an aluminide or silicide layer on said alloyed layer.

- 8. (Original) The method as defined in claim 7, which includes the step of forming a Cr film and an Al film on said platinum-group or refractory metal-Re-Cr alloy, wherein the step of subjecting the alloyed member to an aluminum or silicon diffusion coating includes subjecting said alloyed member with said Cr and Al films to an aluminum diffusion coating at a given high temperature to allow said Cr and Al films to be formed as a Cr-aluminide layer.
- 9. (Original) The method as defined in claim 7, which includes the step of forming a Re film on said platinum-group or refractory metal-Re-Cr alloy, wherein the step of subjecting the alloyed member to an aluminum or silicon diffusion coating includes subjecting said alloyed

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member with said Re film to a silicon diffusion coating to allow said Re film to be formed as a Re-silicide layer.